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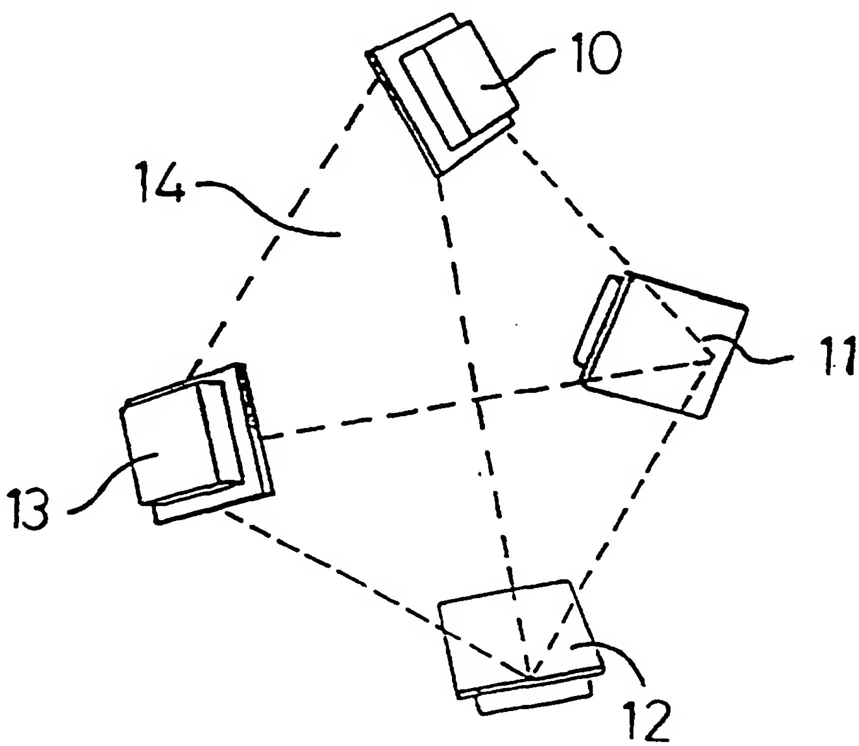
(54) Title: THREE-DIMENSIONAL MEASUREMENT UNIT AND POSITION INDICATOR

(57) Abstract

A 3-D translation and rotation measurement unit and position indicator using linear motion sensors only. The measurement unit comprises at least four linear motion sensors (10, 11, 12, 13; 20, 21, 22, 23, 24, 25) as defined, the sensors being positioned and oriented relative to each other so that one change in motion of the unit produces changing signals from at least two of the sensors and so that other changes in motion perpendicular thereto produce changing signals from sensors which include the previously unaffected sensors. The sensors are mounted on a single body (14), and the measurement unit may be connected to means to provide a 3-D position indicator.



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THREE-DIMENSIONAL MEASUREMENT UNIT AND POSITION INDICATOR

FIELD OF THE INVENTION

This invention relates to a three-dimensional measurement unit, and a three-dimensional position indicator which receives and records measurements from the measurement unit and which is hereinafter referred to as a "3-D indicator".

BACKGROUND TO THE INVENTION

Inertial navigation is widely used for plotting the change in the position of a body (and in conjunction with an indicator for recording the new position reached by the body), and has the recognised advantage that no external reference is needed for specific determination of the new position. Thus the new position of the body is calculated by measuring the changes (translation and orientation) which have occurred since the body moved from a known start position; the new position can be recorded as by the use of a display unit fed from the measurement unit.

However the linear and rotational measurements require accurate instrumentation both to sense the translational movements (linear) and the rotational movements (angular turning rates), and to sum these where necessary e.g where as is usual a succession of movements (forward and perhaps reverse with positive/negative signal changes) has occurred between the initial and final positions of the body.

A three-dimensional measurement unit can also be used to follow vibrations in a structure, and possibly also to control the addition of counter-vibrations whereby to achieve a net vibration reduction. To provide an appropriate counter-vibration control the structure movements would be recorded as they occur by use of the measurement indicator, with its readings perhaps compared to

those from a datum position indicator positioned to be free or substantially free of the vibration movements.

DISCLOSURE OF THE PRIOR ART

Gyroscopes are often used to determine angular turning rates, typically being mounted in a servo-loop to stabilize a frame of reference, accelerometers being mounted on the frame of reference to measure linear movements. Three axes of stabilization are necessary to stabilize a frame of reference, requiring therefore three single-axis gyroscopes, two two-axis gyroscopes or one three-axis gyroscope. Gyroscopes are however relatively heavy and bulky, as well as costly.

Accelerometers are known, responsive to the acceleration of the body, usually in a selected direction. Mechanical accelerometers typically include a hinge, together with a mechanical, optical, inductive or capacitative sensor to detect the motion of the hinge induced by the acceleration. An accurate form of accelerometer with low hysteresis can be provided by a seismic mass (proof mass) suspended from opposite sides by deflectable arms (beam mounted) or from one side by one or more deflectable arms (cantilever mounted); deflection of the arms can be measured by strain gauges attached to or inbuilt into the arms, perhaps with additional stain gauges connected in an electrical bridge circuit so as to discount the effect of movements of the seismic mass other than along a specified axis. A cantilever mounted electronic accelerometer is disclosed in Siemens Automotive L.P. USA Patent 5,412,987, which also discloses electrical bridge circuitry to cancel the signals from other axes.

Other known accelerometers include solid state units of the piezo-electric and piezo-resistive types, and those of the servo (force balanced) type.

Velocity sensors are known, responsive to the velocity of a body relative for example to a surrounding structure or to an adjacent medium. Force, time and length are quantities which can be measured very accurately by direct observation; thus the rate of flow of a liquid relative to a pipe can be accurately determined for example by weighing the discharge of the liquid from the pipe during a timed interval. For convenience and economy however secondary instruments have been developed (velocity sensors), with an accuracy as is well understood by those familiar with the art dependent on their calibration and assumed coefficients.

An inertial measurement unit which provides three-axis acceleration and angular turning rate detection is disclosed in Morrison international patent application PCT/US86/02410 (publication WO 87/03083). Morrison discloses a cubical sensor mass magnetically suspended within a cubical outer housing and free to move relative to the outer housing under acceleration forces. The sensing mass has six sensing and three suspension elements on each of its six faces, opposite corresponding sensing and suspension elements on the outer housing. This arrangement is costly and complicated to assemble, and with thirty six sensing units and eighteen suspension units difficult to calibrate. Both the inner and outer cubic bodies move under acceleration force, and the respective electrical current (sent only to selected suspension elements on the outer cube) is varied to restore the cubes to a required relative position, with a significant power requirement for the relatively bulky and weighty inner cube. The sensitive axes of at least the twenty four sensing elements at the (eight) cube corners are shown to intersect with two others. The accelerometer servo compares net impedance inputs and so will not warn of one

sensor failure. Morrison specifies a dedicated sensor technology, using relatively fragile sensors, and a particular spatial arrangement (defining both the relative sensor spacing and their relative orientation).

A vibration cancellation arrangement was disclosed in the Journal of the American Helicopter Society 29:4 (July 1984) by Val, Gregory and Gupta. However this used a continuous linear analogue approach which was time-invariant and so lacked frequency tracking.

DISCLOSURE OF THE INVENTION

The invention aims to use commercially available sensors, arranged so that the measurement unit is capable of noting 3-D position and 3-D orientation changes. The indicator unit records the measured changes, temporarily or permanently.

The invention aims in one aspect to provide an improved 3-D measurement unit which can be self-relating to a starting datum point, which is easy to use, which can have many external applications, particularly as a hand-held indicator device, and which in a preferred arrangement is based on a structure using linear motion sensors only.

Accordingly, the invention provides a three-dimensional measurement unit comprising at least four linear motion sensors, the sensors being positioned and oriented relative to each other so that a movement in one direction can provide a first set of signals from the sensors and so that a movement in a different direction can provide a second set of signals from the sensors, the sensors providing a set of distinguishable signals for each linear and angular movement characterised in that the sensors are mounted on a single body.

According to another feature, the invention provides a three-dimensional measurement unit comprising at least four linear motion sensors, the sensors being positioned and oriented relative to each other so that one change of motion of the unit produces changing signals from at least two of the sensors and so that other changes of motion perpendicular to said one change of motion produce changing signals from sensors which include previously unaffected sensors such that the signals in combination are responsive to the change in position of the unit relative to a datum position due to the intervening translational and rotational motions of the body from the datum position characterised in that the sensors are mounted on a single body, in that conductor means feed the signals to a signal processing means via a converter, in that the signal processing means and the converter are carried by the body, in that the converter converts the signals to a form readable by the signal processing means, in that calculating means adapted to use the converted signals to calculate motion values are provided, and in that output means direct the motion values to an external system interface.

Normally the signals will be converted from analogue to an appropriate digital form and typical signal processors then include microprocessors, digital signal processors and/or digital logic. There can be a single analogue to digital converter, with sample and hold circuits and a multiplexer, or in a preferred arrangement to avoid offsets and errors which are costly to correct one analogue to digital converter for each sensor. In one embodiment the signals are converted to digital form at the sensor so that the processing is effected on digital signals.

By "linear motion sensor" we mean a device adapted to provide an electrical signal indicating the linear component of velocity or acceleration acting along the sensitive axis of the device. This definition does not exclude devices

which additionally utilise an electrical signal produced along another axis (which might otherwise be ignored as by using an appropriate electrical bridge circuitry as suggested in Siemens US Patent 5,412,978).

It will be appreciated that the sensors may be formed in the substance of the body, e.g. by being etched and diffused or otherwise forming them in a single piece of silicon or other suitable semiconductor whereby the body and sensors become a single structure with discrete sensing areas.

The use of accelerometers which are sensitive to constant as well as varying acceleration (hereafter referred to as "DC sensitive") allows the system to detect orientation with respect to gravity (hereafter referred to as "absolute orientation"). When there is gravitationally induced acceleration the system can therefore detect which way "down" is. Accelerometers which are capable of sensing changes in acceleration only (hereafter referred to as "AC sensitive") will not allow the system to be used to detect absolute orientation; only changes in translation and orientation will be detectable. For the purposes of the following description, when accelerometers are mentioned the use of DC sensitive accelerometers is assumed, since this is the preferred form, although it will be understood that in practice either DC or AC sensitive accelerometers can be used albeit producing different readings.

If velocity sensors are used, when being zeroed the body does not need to be stationary (or to have an assumed velocity) i.e. in order that its relative datum or starting position can be calculated accurately. A velocity sensor will respond to the current velocity of the body carrying the sensors, and using velocity sensors would not therefore introduce an unknown datum error into the subsequent calculations. Furthermore single integrals can be used to calculate body displacement and orientation, both

simplifying the calculations and thus the calculation circuitry, and avoiding the problem of errors from the first integral (conversion of acceleration into velocity) being fed into the second integral (conversion of velocity into displacement). The unit would use lower order error mechanisms and so could be more accurate. However velocity sensors cannot calculate the original orientation of the body i.e. they cannot calculate which is the gravitational direction from observed gravitational and other accelerations.

In specific embodiments 4, 5 or 6 sensors may, for example, be positioned and orientated relative to each other in such a way that signals are produced which may be used to calculate 3-D linear acceleration and 3-D angular acceleration and from which the respective velocities and displacements can be calculated. Examples of suitable arrangements are described below with reference to the drawings. However, it will be appreciated that the invention is not limited to the use of these specific numbers of sensors or their disposition.

Clearly some configurations will not work. For example, four sensors oriented in the same direction or three sensors at rightangles will provide signals from which 3-D position and 3-D orientation cannot both be distinguished and calculated simultaneously or concurrently. Equally clearly, configurations will be preferred which produce signals which, when processed, give large values for linear and angular acceleration. Configurations with four sensors only have for example the advantage of fewer components, but the calculation of position and orientation could be more difficult, requiring in one embodiment more complex circuitry for the automatic calculation of the displacement values; however the same circuitry can often be used but with more complex calculations (algorithms) and less accurate results.

It is an advantage of our invention that proprietary sensors (more or less robust as suited to the application) can be used if an appropriate relative disposition for combined 3-D translational and rotational measurements is selected. Another advantage is that the spacing and/or orientation of the sensors can be altered for different known applications or for superior performance, as well as for ease of manufacture or assembly e.g. automated assembly.

Preferably the sensors e.g. accelerometers, will be selected from those having low linear hysteresis e.g. below 0.0001g, and low angular hysteresis e.g. below 1 minute of arc. Both linear and angular hysteresis contribute towards drift in the measured positional change i.e. in the indicated new 3-D position i.e. each can contribute towards linear and angular drift. Increasing the spacing between the sensors can reduce the effect of linear and angular hysteresis on angular drift and thus will be used whenever possible; however, though increased spacing will not directly result in a corresponding reduced linear drift, this reduction may occur as an indirect result i.e. because increased spacing reduces the effect of linear and angular hysteresis on angular drift, and because a by-product of angular drift is an associated linear drift, then increased spacing will result in an indirect reduction of the linear drift which is due to linear and angular hysteresis. Angular drift causes as a by-product of the calculations an associated linear drift which would be in addition to any other drifts present. The maximum acceptable linear and angular drift rates will condition the choice and positioning of the selected sensors.

SHORT DESCRIPTION OF THE DRAWINGS

The invention is now further described by way of example only with reference to the accompanying drawings in which:-

Fig. 1 is a schematic arrangement showing the use of four accelerometers;

Fig. 2 is a schematic arrangement showing the use of six accelerometers;

Fig. 3 is a block diagram for an arrangement of four accelerometers and a temperature sensor;

Fig. 4 is a flow-diagram of the microprocessor operation for a 3-D indicator constructed according to the arrangement of Figure 3; and

Fig.5 is an alternative block diagram for an arrangement of four accelermeters and a temperature sensor.

DESCRIPTION OF EXEMPLARY EMBODIMENTS

The measurement units described below operate from a "zero" position i.e. a known starting datum or one which can be derived from ancillary measurements. The changes in translational and rotational position from that datum are measured, and usefully are fed to an indicating device e.g. for observation and recording. Also the units have a zero velocity, or a known velocity which is introduced into the datum reading - though if velocity sensors are used instead of accelerometers the start velocity can be calculated by the unit from the velocity sensor signals.

The measurement units can be used in environments which are not stationary relative for example to the earth's surface

or to a stellar position, requiring only that the zero position can be determined or reliably assumed.

Furthermore the measurement unit can be set at a known zero even if the mounting body is vibrating, providing that the vibration is not accompanied by an unknown drift in position i.e. so that the vibrations cancel each other out whereby though there may be AC displacement components there should be minimum unknown DC displacement components to the vibration. The extent to which these considerations do not apply adds to the system drift rate i.e. the presence of unknown DC displacement components during zeroing would not prevent the system functioning but it would reduce the accuracy of the measurements.

In Fig. 1 an arrangement of four accelerometers 10, 11, 12 and 13 is shown, one being oriented to lie in the plane of each face of an equilateral pyramid 14, each placed so that the sensitive axes do not intersect at a common point. Pyramid 14 provides the single body upon which the four sensors are mounted, though in other embodiments the four sensors are formed in the material of the pyramid body 14 or in the surface material of pyramid body 14 i.e. a semi-conductor material.

With such an arrangement of accelerometers mounted on or in the pyramid body with their sensitive axes mutually angled, varying signals will be received from at least three of the sensors, and from all four sensors if the movement is not perpendicular to the sensitive axis of one of the sensors. The components of acceleration can be computed from the respective accelerometers such that body translational and rotational movements are distinguished.

In Fig. 2 an arrangement of six accelerometers 20, 21, 22, 23, 24 and 25 is shown. The accelerometers are arranged in three pairs, each respective pair 20, 21; 22, 23; 24, 25

being mounted in the same plane relative to one of three mutually perpendicular axes x, y and z respectively. Alternatively stated Fig. 2 shows a measurement unit utilising six accelerometers, the accelerometers of a pair (for instance those on the X axis) being arranged to either side of a central plane (plane Y-Z), and with their sensitive axes (showed arrowed) being parallel with that plane(Y-Z), the three planes X-Y,Y-Z,Z-X in this embodiment being mutually perpendicular. Although the sensitive axis of each of the sensors making a pair is parallel to that of the sensitive axis of the other sensor of the pair, this need not be so; thus these extensions of these axes could intersect at a position spaced from the measurement unit, which though not preferred makes accurate assembly of the sensors to a mounting body less critical and thus easier and cheaper.

The spacing between the accelerometers will be increased where possible, in accordance with the body size, to reduce the effect of hysteresis on measurement drift and increase sensitivity to angular acceleration i.e. angular acceleration sensitivity or sensitivity to angular movements (non-steady state) is increased.

The arrangements of both Figs. 1 and 2 have been found in tests to give good results and acceptably large calculation values for linear and angular acceleration. The arrangement of Fig. 2 is, however, preferred since the signals are likely to continue to be easier to process (and so likely also to provide more accurate readings).

The calculation in the microprocessor for the embodiment of Fig. 2 basically comprises, for each pair, firstly taking the processed signal from the first accelerometer and subtracting it from the processed signal of the second accelerometer; the result is a "net" value which is used to calculate the measurement of planar rotation of the pair.

Secondly the signals are also added together and the result is divided by two; from this it is possible to calculate the translational movement in the direction perpendicular to the plane of the pair. Thus the Fig.2 arrangement, with the sensors having non-intersecting sensitive axes, allows a considerable simplification in the measurement unit construction, calibration and measurement calculation.

A systemised signal processing arrangement based on four accelerometers as shown in Fig. 1 plus a temperature sensor is shown in block diagram form in Fig. 3. In an alternative embodiment more than one temperature sensor is used, for instance one for each motion (in this embodiment acceleration) sensor whereby to minimise measurement errors due to thermal differences around the body e.g. before the warm-up gradients have reached steady state or differential environmental heating or cooling.

The system has one channel for each accelerometer and an additional channel for the temperature sensor; when the indicator is energised each channel in this embodiment can produce continuous signals though in an alternative embodiment rapidly repeated intermittent signals are used.

An advantage of utilising one channel for each accelerometer is that failure or malfunction of a sensor can be detected e.g. if no signal is received from an accelerometer despite the indication from other accelerometers that the indicator is translating and rotating, or if no signal is received from that accelerometer within a specified period after start-up. The channel for the sensor 13 is shown surrounded by dotted lines.

Each accelerometer 10, 11, 12 and 13 feeds an electric analogue signal, which changes in value in accordance with the sensed acceleration along its sensitive axis, to a respective amplifier 100, 101, 102 and 103. From the

amplifier, each amplified signal is passed to a respective low pass filter 110, 111, 112 and 113 selected to remove unwanted signal frequencies; the filtering has three principal functions, namely to reduce noise, to prevent aliasing with the analogue to digital converter and to reduce the bandwidth of the system whereby to include only the desired frequencies. The output from each filter is passed to a respective "Sample and Hold" device 120, 121, 122 and 123, which lets the signal pass through to its output unaltered or freezes the signal when the "Sample and Hold" control signal from microprocessor 132 instructs it to do so. The "Sample and Hold" devices thus ensure that the signals from all the acceleration channels presented through the multiplexer 130 to the analogue to digital converter 131 relate to the same point in time.

The output of each "Sample and Hold" device is fed to one of the inputs of the multiplexer 130. The microprocessor 132 by means of the "channel select" signal selects each channel in turn. Multiplexer 130 connects the requested input channel to its single output channel and the signal is fed to the analogue to digital converter 131 where it is converted to digital form and fed to the microprocessor 132.

Temperature sensor 133 produces signals of a relatively slow changing nature so that a "Sample and Hold" device is not required on this channel. Its signal is amplified by amplifier 104 and fed directly to multiplexer 130.

At fixed time intervals, the system converts, one at a time, the signal values of all channels into digital form and then performs the required calculations in the microprocessor.

To accommodate variations in mechanical sensor alignment which are due to production tolerances, and variations in sensor behaviour which are due to non-ideal performance (e.g. parameters which vary from device to device or vary

with temperature etc.), the system is calibrated in advance of normal use in such a way that the variations can be taken into account during the normal use calculations (to determine the new position and orientation). The calibration process values are stored in calibration memory 134 and are accessed when the calculations are performed.

In this embodiment during initial calibration there is measured (and compensated) at least :-

(i) Accelerometer gain i.e. sensitivity, versus temperature;

(ii) Accelerometer zero point versus temperature;

(iii) Accelerometer orientation versus temperature (to compensate for the thermal expansion of the sensor mountings etc);

(iv) Accelerometer position versus temperature (also to compensate for thermal expansion of the mountings etc);

(v) Signal processing gains and offsets, versus temperature;

(vi) Accelerometer linearity; and

(vii) Accelerometer frequency response (as necessary, depending on the type of accelerometer chosen).

The program memory 135 stores the program which performs functions related to control of the signal conversion process, calculation of position and orientation and communication of results to an external system.

The scratch-pad memory 136 is used to store temporary values required by calculations during normal processing.

The converted signals are fed from microprocessor 132 to an external system interface 137. In addition to 3-D position and 3-D orientation, it is possible to transmit other derived information which may be of use to an external

system (e.g. 3-D linear and 3-D angular acceleration, 3-D linear and 3-D angular velocity, temperature, frequency - perhaps in the form of a frequency spectrum, elapsed time etc.).

Fig. 4 shows an example of the sequence of operations performed by the microprocessor and is described below with reference to the processing operations required to calculate 3-D position and 3-D orientation using an arrangement of multiple DC sensitive linear accelerometers.

Processing begins when the system is switched on - step S1. The system is put into a state ready for processing by the initialisation - step S2; this involves resetting the hardware and setting software variables into their required initial values. The remainder of processing is performed in two blocks (block A and block B). Block A is used to establish which way "down" is, by finding the 3-D orientation in which gravity is constantly acting on the device. When this has been done, a continuous cycle of determining 3-D position and 3-D orientation is performed as in block B.

Block A

In step S3 the sensors (both temperature and acceleration) are read and in step S4 the calibration corrections are then applied. In step S5 the corrected values are then used to calculate the 3-D orientation of gravity acting on the accelerometers. Step S6 determines whether the error value for the direction of gravity is acceptably small; the initial value of the error signal is set in step S2 to be large, with the effect that steps 3 to 6 are repeatedly performed until the 3-D orientation of gravity acting on the accelerometers is calculated to an acceptable accuracy. When the required accuracy has been achieved, processing

switches from Block A to Block B due to step S6 terminating the loop.

Block B

In step S7, the sensors are read (as in step S3) then the calibration corrections are applied in step S8. Step S9 removes the effect of gravity, which is constantly acting on the accelerometers, from the calculations so that the resulting values are then due only to movement or rotation of the device as a whole. In step S10 these values are then used to calculate by means of matrix transformation and double integral, the difference in position and orientation of the device since processing started in block B. The newly calculated 3-D position and 3-D orientation change is output to an external system using a suitable method (e.g. serial wire connection, microprocessor interface etc.) as in step S11. Steps S7 to S11 are repeated at fixed intervals of time to produce a series of 3-D positions and 3-D orientations. The length of the time interval is small enough so that the system can accurately track any movements or rotations of interest without errors building up due to loss of information.

Applying Corrections

The accelerometer readings obtained in steps S3 and S7 are corrected using values obtained during a calibration process so as to remove the effect of variations in accelerometer performance due to production tolerances of a mechanical and electrical nature. When the following typical corrections have been applied, the corrected readings more closely reflect the values that would be obtained from accelerometers which give ideal readings and are perfectly placed relative to one another.

Corrections

Amplifier offsets versus temperature.

"Sample and Hold" offsets versus temperature and signal level.

Accelerometer 3-D positional and 3-D angular misalignment.

Accelerometer gain versus temperature.

Accelerometer zero point versus temperature.

Accelerometer off-axis sensitivity versus 3-D angle of acceleration.

Sensor linearity and device 3-D thermal behaviour (i.e. the heating and cooling gradients across the body, and perhaps the sensors, for instance in response to switch on, or external heating sources)

In an alternative embodiment arrangements are made for re-calibration after initial use by the customer. These cailibrations would take into account alterations in performance e.g. over time, and for DC units alterations due to variations in the local value of gravity.

Whilst separate accelerometers are preferred, specifically separate seismic masses for each of the X,Y and Z axes, since this permits flexible positioning of the accelerometers to suit the needs of individual applications within the constraint of body size and shape, as well as often easing their manufacture, accelerometers using a single seismic mass can be used.

An arrangement based on four accelerometers arranged as shown in Fig.1 plus a temperature sensor is shown in Fig.5. The system has one channel per accelerometer (the channel for sensor 13 is shown surrounded by dotted lines) and an additional channel for the temperature sensor, each channel producing digital signals.

Thus each accelerometer 10,11,12 and 13 feeds a changing electric analogue signal relative to its acceleration along its respective axis to an amplifier 200,201,202 and 203 respectively. From the amplifier, each amplified signal is passed to a low pass filter 210,211,212 and 213 respectively similar to that of the Fig.3 embodiment. The output from each filter is passed to an analogue to digital converter device 220,221,222 and 223 respectively. This device converts the signal to digital form and feeds the digital number to the conversion controller 230. The conversion controller ensures that conversions take place at repeated fixed intervals of time and that the conversion which is performed in each channel's analogue to digital converter takes place at the same point in time. The period of time from one conversion time to the next is referred to as a conversion cycle. The signals in converted digital form are stored in the conversion controller ready to be sent to the microprocessor 232 before the next analogue to digitial conversion takes place. In addition to converting the signal from its analogue form to digital form, a method of correcting offsets is used in order to reduce the size of offsets which are present in the sensor being incorporated in the signal which is converted to digital form.

The microprocessor will from time to time read from its calibration memory 234 offset correction values which need to be applied to the sensor (such as those outlined above). This is necessary for example when temperature changes produce zero offsets in the sensor. These offset correction values are stored by the microprocessor in the conversion controller 230. During each conversion cycle which may for convenience be synchronised with the analogue to digital conversion cycle, the offset correction values stored in the conversion controller 230 are passed to a digital to analogue device 240,241,242,243 respectively. This converts the stored digital offset correction number from digital to analogue form. This analogue signal is fed to an amplifier

250,251,252,253 respectively which changes the signal to the required size. This is then fed to a low pass filter 260,261,262,263 respectively which removes the unwanted high frequency components from the analogue signal. This filtered signal is then applied to the sensor signal by feeding it into the sensor or mixing it with the output of the sensor. This ensures that offsets in each sensor 10,11,12 and 13 which make the sensor signal depart from a zero mean are corrected for and therefore the full range of the analogue converters can be used.

By not using sample and hold devices and a multiplexer for signals coming from the sensors, the Fig.5 embodiment removes offsets from the system which might otherwise be difficult to correct.

Temperature sensor 273 produces signals of a relatively slow changing nature so that a Sample and Hold device is not required on this channel (see also the Fig.3 enbodiment). The temperature sensor's signal is amplified by amplifier 274 and fed to an analogue to digital converter 275 and then fed directly to conversion controller 230.

When each conversion cycle is complete the signal values of all analogue to digital input channels are read by the microprocessor 232 in digital form and then the required calculations are performed in the microprocessor.

The arrangement of Fig.5 has a calibration memory 234, a program memory 235, a scratch pad memory 236 and an external interface 237, which components function in a similar fashion, and for similar purposes, as the equivalent components of the arrangement of Fig.3.

The invention can be used in a wide variety of applications which require a 3-D indicator, for example:-

Input devices in virtual reality, CAD and remote manipulation systems;

Sensing devices in test and measurement equipment;

Industrial uses, including vibration counterdamping.

Motion capture (the addition of one or more measurement units to a body e.g. human, to record movement, as a way of controlling characters in computer games etc).

CLAIMS

1. A three-dimensional measurement unit comprising at least four linear motion sensors (10,11,12,13; 20,21,22,23,24,25), the sensors being positioned and oriented relative to each other so that a movement in one direction can provide a first set of signals from the sensors and so that a movement in a different direction can provide a second set of signals from the sensors, the sensors providing a set of distinguishable signals for each linear and angular movement characterised in that the sensors are mounted on a single body (14).

2. A three-dimensional measurement unit comprising at least four linear motion sensors (10,11,12,13; 20,21,22,23,24,25), the sensors being positioned and oriented relative to each other so that one change of motion of the unit produces changing signals from at least two of the sensors and so that other changes of motion perpendicular to said one change of motion produce changing signals from sensors which include previously unaffected sensors such that the signals in combination are responsive to the change in position of the unit relative to a datum position due to the intervening translational and rotational motions of the body from the datum position characterised in that the sensors are mounted on a single body (14), in that conductor means feed the signals to a signal processing means (132,232) via a converter (131,220,221,222,223), in that the signal processing means and the converter are carried by the body, in that the converter converts the signals to a form readable by the signal processing means, in that calculating means adapted to use the converted signals to calculate motion values are provided, and in that output means direct the motion values to an external system interface (137,237).

3. A measurement unit according to Claim 2 characterised in that the sensor signals are converted from an analogue to a digital form, and in that the signal processing means is selected from a microprocessor (132,232) and a digital signal processor.

4. A measurement unit according to Claim 1 or Claim 2 characterised in that the sensors are formed in the substance of the body (14) and in that the sensors are formed by etching and diffusion into a single piece of silicon whereby the body and sensors become a single structure with discrete sensing areas.

5. A measurement unit according to claim 1 or claim 2 characterised in that the linear motion sensors are accelerometers sensitive both to constant and to varying acceleration whereby to allow determination of the gravitational direction.

6. A measurement unit according to claim 1 or claim 2 characterised in that there are four linear motion sensors (10,11,12,13), each sensor having a sensitive axis, each sensor being responsive to acceleration along its sensitive axis, none of the sensitive axes intersecting.

7. A measurement unit according to claim 1 or claim 2 characterised in that there are six accelerometers (20,21,22,23,24,25) arranged in three pairs, the accelerometers of each pair being arranged to either side of a central plane (Y-Z,X-Z,X-Y) and with their sensitive axes parallel to that plane, the three planes being mutually perpendicular.

8. A measurement measurement unit according to claim 1 or claim 2 characterised in that a separate channel is provided for each signal.

9. A measurement unit according to claim 1 or claim 2 characterised in that a channel multiplexer (130) receives the sensor signal or a derivative thereof by way of a sample and hold device (120,121,122,123) adapted to identify the converted sensor signal or its derivative received at a point in time, the signals from different sensors being received by way of different channels, the channel multiplexer receiving also a temperature signal or a derivative thereof from a temperature sensor (133).

10. A method of using a measurement unit according to claim 1 or claim 2 characterised in that at least four sensors are positioned and orientated relative to each other on the body in such a way that signals are produced which may be used to calculate 3-D linear acceleration and 3-D angular acceleration, submitting the signals separately to a processor (132,232), and processing the signals to obtain a velocity and displacement calculation.

11. A three-dimensional position indicator fed by signals obtained from a measurement unit according to any of claim 1-9.

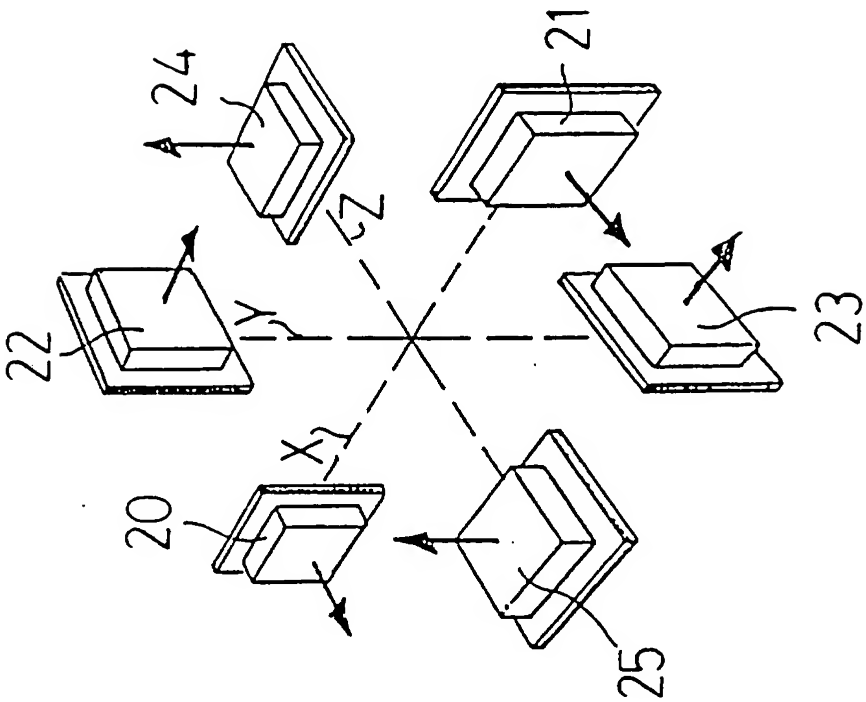

FIG 2

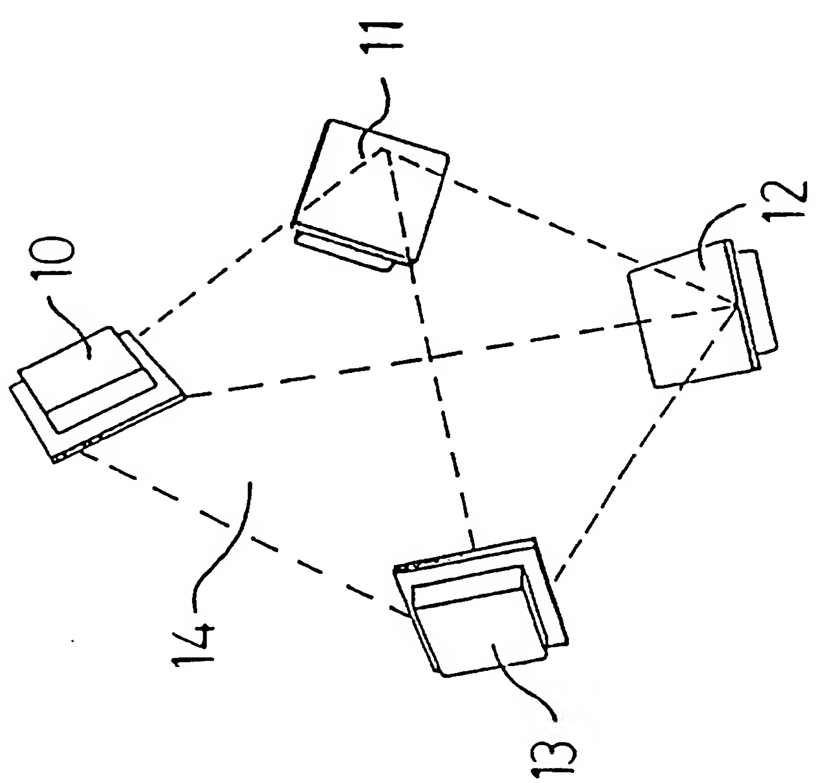

FIG 1

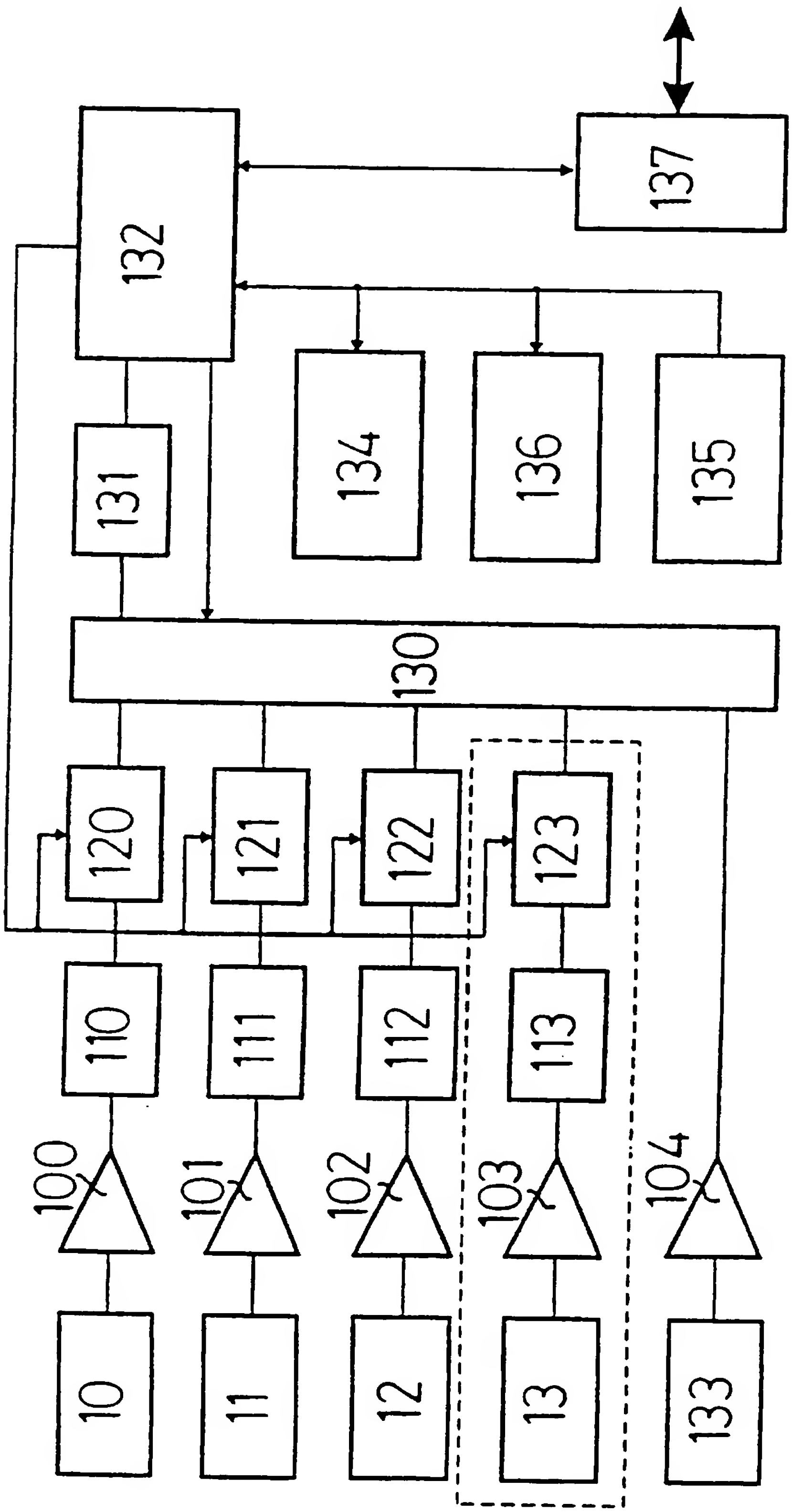
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FIG 3

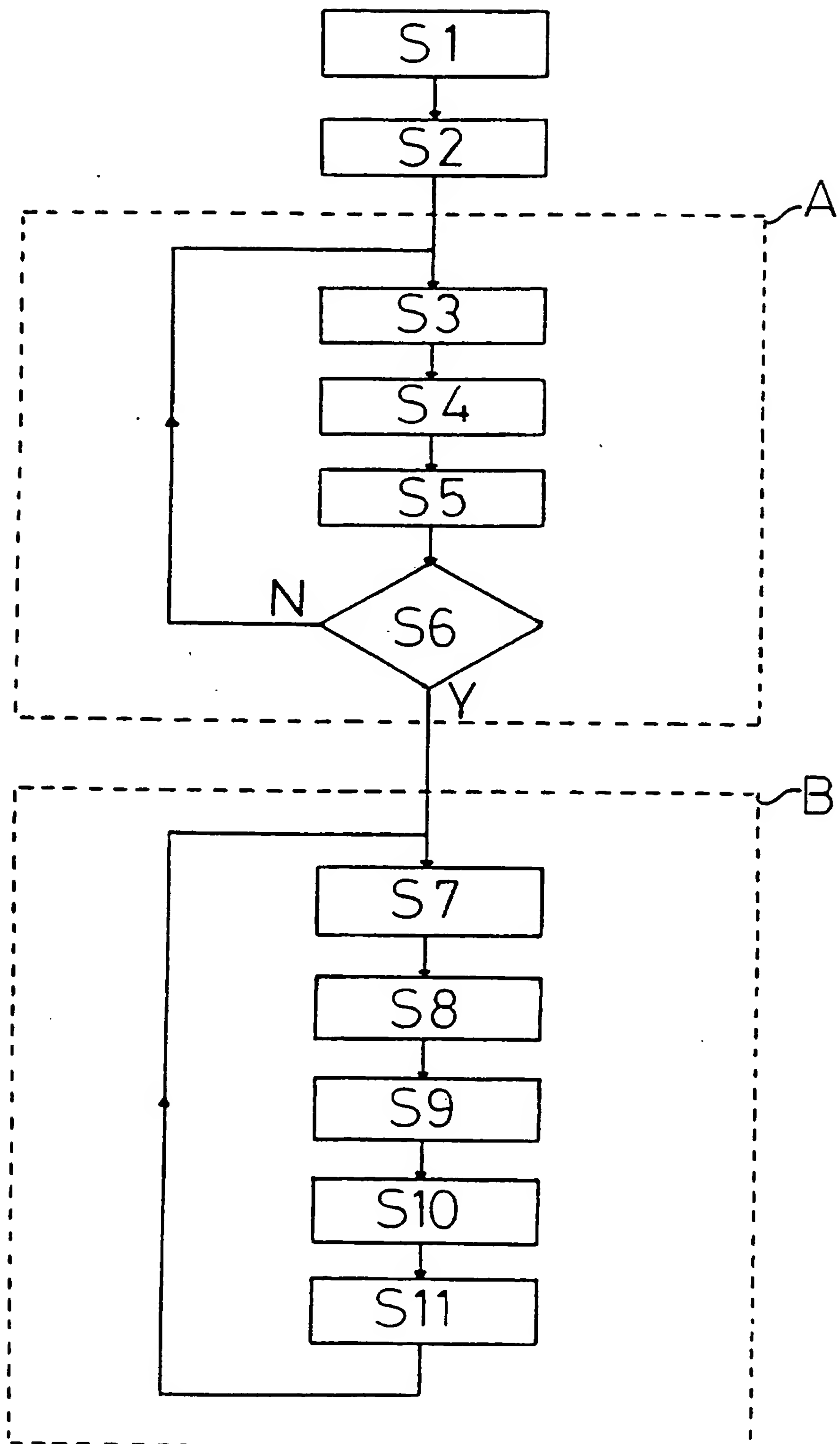

FIG 4

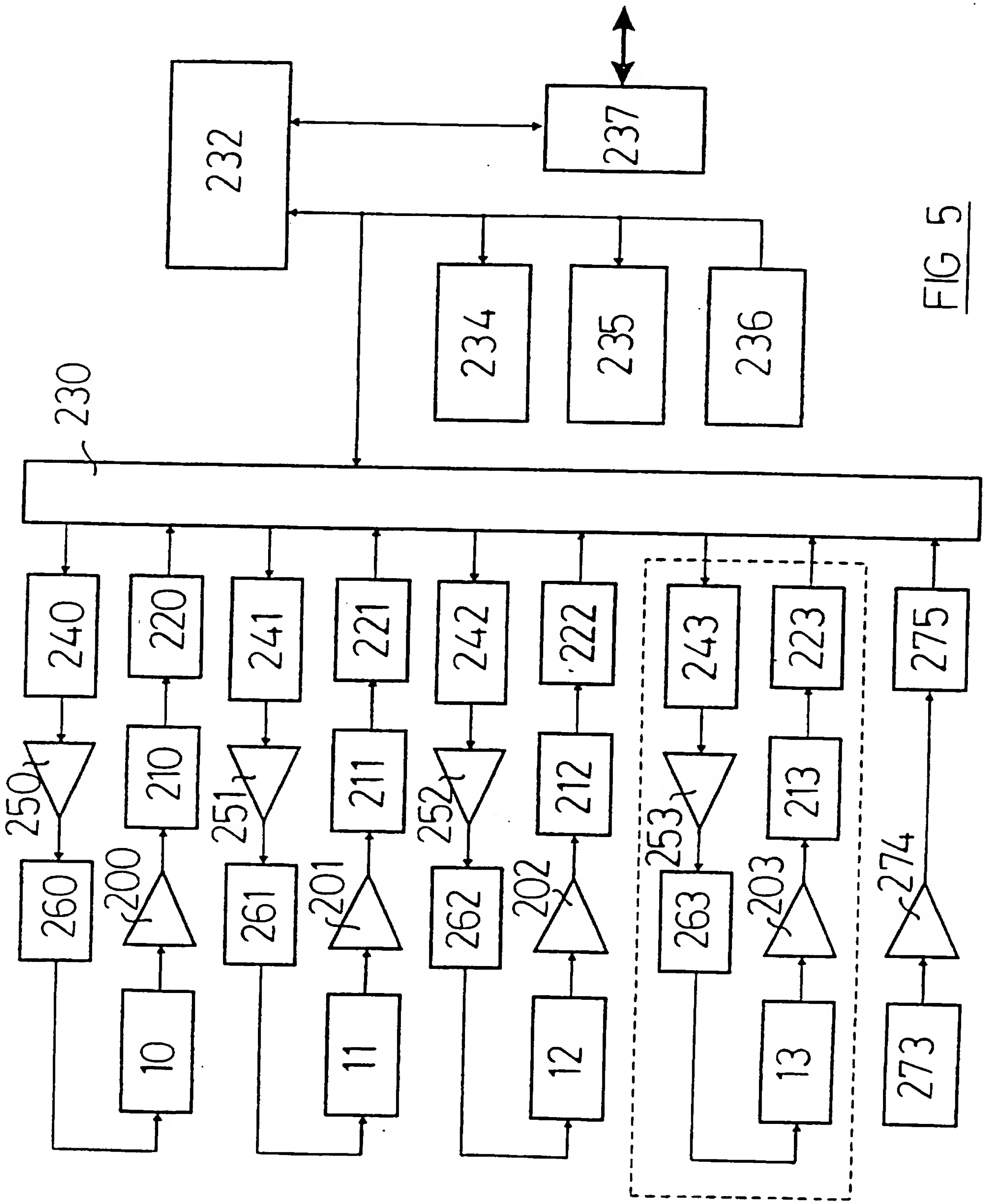
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FIG 5

INTERNATIONAL SEARCH REPORT

International Application No
PCT/GB 95/02004

A. CLASSIFICATION OF SUBJECT MATTER
IPC 6 G01C21/16 G01P15/00

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
IPC 6 G01C G01P

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category *	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	GB,A,2 146 776 (FERRANTI PLC) 24 April 1985 see page 2, line 64 - line 89; figures ---	1-3,5,7, 8,10,11
X	EP,A,0 556 487 (FOKKER SPACE & SYSTEMS B V) 25 August 1993 see abstract; figure 7 ---	1,5,10, 11
X	JOURNAL OF GUIDANCE, CONTROL, AND DYNAMICS, MARCH-APRIL 1994, USA, vol. 17, no. 2, ISSN 0731-5090, pages 286-290, JENG-HENG CHEN ET AL 'Gyroscope free strapdown inertial measurement unit by six linear accelerometers' see the whole document --- -/--	1,5,10, 11

[X] Further documents are listed in the continuation of box C.

[X] Patent family members are listed in annex.

* Special categories of cited documents :

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"O" document referring to an oral disclosure, use, exhibition or other means

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"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

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"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
14 November 1995	14. 12. 95

Name and mailing address of the ISA	Authorized officer
European Patent Office, P.B. 5818 Patentlaan 2 NL - 2280 HV Rijswijk Tel. (+31-70) 340-2040, Tx. 31 651 epo nl, Fax (+31-70) 340-3016	Hoekstra, F

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Inter nal Application No
PCT/GB 95/02004

C.(Continuation) DOCUMENTS CONSIDERED TO BE RELEVANT

Category *	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
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A	DE,U,91 13 744 (SMT & HYBRID GMBH) 16 January 1992 see the whole document -----	1

1

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INTERNATIONAL SEARCH REPORT

Information on patent family members

International Application No
PCT/GB 95/02004

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		JP-B-	4065963	21-10-92
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		US-A-	5408879	25-04-95
DE-A-3600763	16-07-87	NONE		
DE-U-9113744	16-01-92	NONE		